TITLE OF THE INVENTION

ALIGNMENT APPARATUS AND

EXPOSURE APPARATUS USING THE SAME

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FIELD OF THE INVENTION

The present invention relates to an alignment apparatus capable of high-accuracy alignment and an exposure apparatus using the same.

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BACKGROUND OF THE INVENTION

A conventional example of a stage mechanism which has a plate-like member as a movable portion to align the movable portion at a predetermined position in an

15 in-place direction is disclosed in a patent publication (Japanese Patent Laid-Open No. 8-006642). In the disclosed arrangement, only a plate-like member which holds a workpiece is two-dimensionally moved using a plane pulse motor as a driving source. This method

20 moves only the plate-like member as the movable portion and thus is suitable for reducing the size and weight of a stage movable portion.

Fig. 24 is a view showing the arrangement of a movable element in a conventional stage mechanism. An

25 air supply hole 60 and units 52, 54, 56 and 58 each having coil-wounded inductor toothed cor s ar formed in a box-like member 22 to constitute a movable

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element.

Fig. 25 is a view showing the arrangement of part of a stator in the conventional stage mechanism. The stator is formed as a plate-like member 24, and

5   magnetic projections 72 are two-dimensionally formed on a magnetic base 70. A space between the projections 72 is filled with a resin 74.

Fig. 26 is a sectional view of the stator and movable element in the conventional example. The

10   movable element further comprises permanent magnets 80 and 82, each of which serves as the thrust source of the movable element and at the same time generates a suction force between the movable element and the stator. Air supplied from the air supply hole 60 of

15   the movable element generates an air pressure between the movable element and the stator. The air pressure and suction force become well balanced, thereby allowing the movable element to levitate above apart from the stator.

20   The units 54 and 56 each having coil-wounded inductor toothed cores generate a thrust in the first direction while the units 52 and 58 generate a thrust in the second direction perpendicular to the first direction due to Sawyer's principle. This enables the

25   movable element to freely generate a thrust in the first or the second direction and move two-dimensionally.

However, in th conventional arrangement, the movable element levitates by the air pressure and cannot be used in a vacuum. Also, the stage mechanism is driven by a pulse motor scheme based on Sawyer's

5 principle, and vibrations are likely to be transmitted from the stator both in magnetic gap and traveling directions. This makes it impossible to perform high-accuracy position control.

The movable element includes coils and trailing

10 power cables for supplying power. For this reason, the movable element is susceptible to disturbance by the cables. This also makes it impossible to perform high-accuracy position control.

In addition, the arrangements shown in Figs. 24

15 to 26 can generate a thrust only in the first and second directions perpendicular to each other of the in-place direction and cannot perform tilt correction and position control in a rotational direction to control the posture of the stage mechanism. For this

20 reason, they cannot be used in an apparatus which requires a precise posture and high alignment accuracy, such as a semiconductor exposure apparatus. If they are used, a fine adjustment stage needs to be separately provided to control the posture in the

25 rotational direction. This increases the complexity of the stage m chanism.

SUMMARY OF THE INVENTION

The present invention has been proposed to solve the conventional problems, and has as its object to provide an alignment apparatus which solves the
5   problems, and the like.

According to the present invention, the oregoing object is attained by providing an alignment apparatus which generates a driving force between a plate-like movable element and a stator facing the movable element
10   to control alignment of the movable element, comprising: movable element magnets which are arrayed in a plate-like plane of the movable element in accordance with an array cycle and are magnetized in predetermined directions; stator coils which are
15   arrayed at intervals corresponding to the array cycle; and a current controller which supplies control currents having phase differences to each pair of adjacent ones of the stator coils to generate a driving force for driving the movable element between the
20   movable element magnets and the stator coils facing the movable element magnets.

Other features and advantages of the present invention will be apparent from the following descriptions taken in conjunction with the accompanying
25   drawings, in which like reference characters designate the same or similar parts throughout the figures thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification,
5   illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

Figs. 1A and 1B are views for explaining an alignment apparatus according to an embodiment of the
10   present invention;

Fig. 2 is an enlarged view of the arrangement of fixed coils according to the embodiment;

Figs. 3A and 3B are views for explaining the arrangement of the fixed coils according to the
15   embodiment;

Figs. 4A and 4B are views showing the arrangement of permanent magnet arrays 114 on a movable element 110;

Fig. 5A is a view for explaining the generation
20   principle of a translational force and a levitation force;

Fig. 5B is a control block diagram for controlling to drive the movable element 110 according to the embodiment;

25   Figs. 6A and 6B are views for explaining switching of energization for a coil array to generate a translational force;

Figs. 7A and 7B are vi ws for explaining switching of energization for a coil array to generate a levitation force;

Fig. 8 is a view for explaining control for

5 generating moments about the Z-axis to control rotation;

Fig. 9 is a view for explaining control for generating moments about the X-axis to control rotation;

10 Fig. 10 is a view for explaining control for generating moments about the Y-axis to control rotation;

Figs. 11A and 11B are views showing a modification of the embodiment wherein coil arrays are

15 stacked in a different manner;

Fig. 12 is a view for explaining control of translational driving in the Y-axis direction and rotational driving about the Z-axis in the modification;

20 Fig. 13 is a view for explaining control of translational (levitation) driving in the Z-axis direction and rotational driving about the X-axis in the modification;

Fig. 14 is a view for explaining control of

25 translational driving in the X-axis direction and rotational driving about the Z-axis in th modification;

Fig. 15 is a view for explaining control of translational (levitation) driving in the Z-axis direction and rotational driving about the Y-axis in the modification;

5   Fig. 16A is a view showing an arrangement wherein a twin-stage alignment apparatus having two movable elements and a stator according to the arrangement of the embodiment or modification is applied to a semiconductor exposure apparatus;

10   Fig. 16B is a flow chart for explaining the flow of a device manufacturing process;

Figs. 17A and 17B are views for explaining the arrangements of coil arrays for driving the twin stage in application to the semiconductor exposure apparatus;

15   Fig. 18A and 18B are views for explaining operation of the twin stage in an application to the semiconductor exposure apparatus;

Fig. 19 is a view for explaining operation of the twin stage in an application to the semiconductor

20 exposure apparatus;

Figs. 20A and 20B are views showing modifications of the arrangement of movable element magnets;

Figs. 21A and 21B are views showing modifications of the arrangement of movable element magnets;

25   Fig. 22 is a view showing a structure for cooling coils;

Fig. 23 is a view showing a structure for cooling

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coils;

Fig. 24 is a view showing the arrangement of part of a movable element in a conventional stage mechanism;

Fig. 25 is a view showing the arrangement of part
5   of a stator in the conventional stage mechanism;

Fig. 26 is a view showing sections of the stator and movable element in the conventional stage mechanism;

Fig. 27 is a view showing another modification of
10   the arrangement of movable element magnets;

Fig. 28 is a view showing still another modification of the arrangement of movable element magnets; and

Fig. 29 is a view showing still another
15   modification of the arrangement of movable element magnets.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

A preferred embodiment of the present invention
20   will now be described in detail in accordance with the accompanying drawings.
<Embodiment>

An embodiment according to the present invention will be described with reference to Figs. 1A and 1B.
25   Fig. 1A is a view showing a state wherein a movable element 110 is aligned in the X-Y plane of a stator 100. The movable elem nt 110 is implemented as a

plate-like member. Fig. 1B is a view showing the
relationship between the stator and the movable element
as seen in the direction of the X-Z plane. The movable
element 110 comprises a top plate 112 almost in the

5   shape of a rectangular parallelepiped and a plurality
of permanent magnet arrays 114 arranged below the top
plate. The top plate 112 is desirably made of a
substance having high specific rigidity such as
ceramic.

10   The stator 100 comprises a base 118 and six
layers of coils 116 fixed on the base. Each layer
constituting the six layers of coils 116 comprises a
plurality of almost oblong coils (116a and 116b), as
shown in Fig. 3A or 3B. Each almost oblong coil is

15   arranged such that its linear portion is almost
parallel to the X or Y direction. The arrangement of
Fig. 1B has three layers each comprising almost oblong
coils whose linear portions are parallel to the X
direction and three layers each comprising almost

20   oblong coils whose linear portions are parallel to the
Y direction. That is, the arrangement has an equal
number of layers both in the X and Y directions.
Fig. 2 is an enlarged view of the stacked state of
coils with a focus on a portion A in Fig. 1B.

25   <Explanation of Stator Coil>
        The sixth coil array is arranged on the base
member 108 through an insulating sh et (not shown).

The sixth coil array is a coil layer comprising almost oblong coils whose linear portions are parallel to the X direction and is used for driving in the ωx direction.

5   The fifth coil array is arranged on the sixth coil array through an insulating sheet (not shown). The fifth coil array is a coil layer comprising almost oblong coils whose linear portions are parallel to the Y direction and is used for driving in the ωy

10   direction.

The fourth coil array is arranged on the fifth coil array through an insulating sheet (not shown). The fourth coil array is a coil layer comprising almost oblong coils whose linear portions are parallel to the

15   X direction and is used for driving in the ωz direction.

The third coil array is arranged on the fourth coil array through an insulating sheet. The third coil array is a coil layer comprising almost oblong coils

20   whose linear portions are parallel to the Y direction and is used for driving in the Z direction.

The second coil array is arranged on the third coil array through an insulating sheet. The second coil array is a coil layer comprising almost oblong

25   coils whose linear portions are parallel to the X direction and is used for driving in the Y direction.

The first coil array is arranged on the second

coil array through an insulating sh et. The first coil
array is a coil layer comprising almost oblong coils
whose linear portions are parallel to the Y direction
and is used for driving in the X direction.

5   <Explanation of Movable Element>

Figs. 4A and 4B are views showing the arrangement
of the permanent magnet arrays 114 on the movable
element 110. The plurality of permanent magnet arrays
114 are arranged below the top plate 112 (Fig. 4A).

10 Each permanent magnet array 114 comprises six types of
magnets: one magnetized upward in the Z direction; one
magnetized downward in the Z direction; one magnetized
at an angle of 45° with respect to the X direction; one
magnetized at an angle of 135° with respect to the X

15 direction; one magnetized at an angle of -135° with
respect to the X direction; and one magnetized at an
angle of -45° with respect to the X direction.

Each magnet magnetized upward in the Z direction
is marked with a symbol formed by inserting "✕" into "

20 ○" (e.g., 115a in Fig. 4B); and each magnet magnetized
downward in the Z direction, a symbol formed by
inserting " · " into "○" (115b in Fig. 4B).

Each magnet magnetized at an angle of 45° (115c
in Fig. 4B), an angle of 135° (115d in Fig. 4B), an

25 angle of -135° (115e in Fig. 4B), or an angle of -45°
(115f in Fig. 4B) with respect to the X direction is
marked with an arrow pointing in a corresponding

direction.

In Fig. 4B, a magnetic flux facing downward in the Z direction is generated near each magnet magnetized upward in the Z direction while a magnetic

5 flux facing upward in the Z direction is generated near each magnet magnetized downward in the Z direction. A magnetic flux at an angle of -135° with respect to the X direction is generated near each magnet magnetized at an angle of 45° with respect to the X direction while a

10 magnetic flux at an angle of -45° with respect to the X direction is generated near each magnet magnetized at an angle of 135° with respect to the X direction. Similarly, a magnetic flux at an angle of 135° with respect to the X direction is generated near each

15 magnet magnetized at an angle of -45° with respect to the X direction while a magnetic flux at an angle of 45° with respect to the X direction is generated near each magnet magnetized at an angle of -135° with respect to the X direction. This is because a magnet

20 in an array of magnets having magnetization directions and arrayed in a horizontal plane generates outside the magnet a magnetic flux in a direction opposite to the magnetization direction of the magnet.

The magnets magnetized in the Z direction are

25 arranged both in the X and Y directions at intervals of L and are arranged in their diagonal directions at int rvals of ($\sqrt{2}$) x L. In the diagonal directions,

the magnets magnetized upward in the Z direction and
those magnetized downward in the Z direction are
alternately arranged at intervals of $(\sqrt{2}/2) \times L$.

The magnets 115c magnetized at an angle of 45°
5   with respect to the X direction and the magnets 115e
magnetized at an angle of -135° with respect to the X
direction are alternately arranged between the magnets
115a magnetized upward in the Z direction and the
magnets 115b magnetized downward in the Z direction.

10   The magnets 115f magnetized at an angle of -45°
with respect to the X direction and the magnets 115d
magnetized at an angle of 135° with respect to the X
direction are alternately arranged between the magnets
115a magnetized upward in the Z direction and the
15   magnets 115b magnetized downward in the Z direction.
This arrangement is known as a so-called Halbach array.

Fig. 4B is a view of the movable element 110 as
seen from below. Each magnetic flux facing downward in
the Z direction (a magnetic flux directed upward from
20   the drawing surface of Fig. 4B) is strengthened by
magnetic fluxes gathering from four directions (±45°
or ±135° with respect to the X-axis direction) while
each magnetic flux facing upward in the Z direction (a
magnetic flux directed downward from the drawing
25   surface) is strengthened by magnetic fluxes dispersing
in the four directions. On the other side, i.e., at
the joint between the magnets and the top plate 112,

magnetic fluxes cancel each other, and the magnetic flux distribution becomes almost zero.

On the side in which the stator 100 and movable element 110 face each other, the magnets magnetized in
5 the ±Z directions as well as the magnets magnetized at angles of ±45° or ±135° with respect to the X direction are arranged both in the X and Y directions at intervals of L. For this reason, the magnetic flux densities of the vertical (Z-direction) and horizontal
10 (±45° or ±135° with respect to the X direction) directions generated in the X or Y direction have almost sine wave distributions as the function of the cycle of L.

The vertical magnetic flux density and the
15 horizontal magnetic flux density are out of phase with each other by L/4. Assuming that the cycle of L is 360°, the peak position of the vertical magnetic flux density distribution and the horizontal magnetic flux density distribution are out of phase with each other
20 by 90° (= 360°/4).

Referring to Fig. 4B, there are defective portions A and B in the upper right and lower left corners on a diagonal line, respectively. The defective portions A and B contribute to generation of
25 moments in the ωz direction (to be described later). As shown in Fig. 4B, there ar also three defective regions (regions C, D, and E) in th X direction and

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three defective regions (regions F, G, and H) in the Y

direction, in addition to the defective portions on the

diagonal line. These regions are so controlled as to

prevent, without fail, coils facing them from being

5   energized (to be described later). They do not greatly

contribute to a thrust, and thus no magnets are

attached to them for the purpose of reducing the

weight. Consequently, 14 magnetic units (to be

referred to as "small magnet units" hereinafter) are

10   arranged on the lower surface of the top plate 112.

Each magnetic unit comprises 33 magnets in total: four

magnets magnetized in the +Z direction; four magnets

magnetized in the -Z direction; nine magnets magnetized

at an angle of -45° with respect to the X direction;

15   six magnets magnetized at an angle of 45° with respect

to the X direction; six magnets magnetized at an angle

of 135° with respect to the X direction; and four

magnets magnetized at an angle of -135° with respect to

the X direction.

20   <Generation Principle of Translational force and

Levitation Force>

The generation principle of a translational force

and levitation force will be described with reference

to 51a and 51b in Fig. 5A. The basic principle is

25   based on a Lorentz force using the Fleming's rule.

Each coil is arranged such that its linear portion is

parallel to the X or Y direction. For this reason,

when a current is suppli d to coils in the vertical
(Z-direction) magnetic flux density, a translational
force is generated in the X or Y direction while a
current is supplied to the coils in the horizontal

5   magnetic flux density, a levitation force or a force in
a direction opposite to the levitation force is
generated. Reference numeral 51a in Fig. 5A denotes a
view of the second coil array (see Fig. 2) and the
surface of the top plate 112 on which the magnetic

10 arrays are arranged as seen from below in the Z-axis
direction. As described above, the second coil array
is a coil array layer comprising almost oblong coils
whose linear portions are parallel to the X direction.
The span of the linear portion of each almost oblong

15 coil is half the magnet cycle of L (Fig. 4B), i.e.,
L/2. Each two adjacent almost oblong coils are spaced
apart from each other by (3/4) x L. Assuming that the
cycle of L is 360°, the adjacent almost oblong coils
are out of phase with each other by (3/4) of the cycle

20 of L, i.e., 270°.

Reference numeral 51b in Fig. 5A is a view
showing the relationship between the layout of the
almost oblong coils and their phases. Assume that a
certain coil (e.g., a coil 150a in the view 51a of

25 Fig. 5A) is located on the X-axis (= phase of 0°) and
is used as a reference. The phase of an adjacent coil
150b shifts by 270° and r ach s a point A2 in th view

51b of Fig. 5A. The phase of a coil 150c shifts from that of the coil 150b by 270° and reaches a point B2 in the view 51b of Fig. 5A. For the coil 150a, the phase is shifted 180° with respect to 0° in the X-axis. The

5   phase of a coil 150d adjacent to the coil 150c shifts from that of the coil 150c by 270° and reaches a point C2 in the view 51b of Fig. 5A. The coil 150d has a phase of 90° with reference to the coil 150a.

A coil 150e adjacent to the coil 150d has a phase

10   of 270° with reference to the coil 150d, and the phase reaches a point D2. In this case, the coil 150a and coil 150e are in phase with each other.

If coils are alternately wound in opposing directions or control is performed such that supplied

15   currents flow through the coils alternately in opposing directions, the coils can act as if each coil has either of two phases of 0° and 90°. In the view 51a of Fig. 5A, currents are controlled to flow alternately in opposing directions, and coils to which reverse

20   currents are supplied are marked with a symbol "-" (minus). Apparently, a current to be supplied to each coil has either of two phases, A-phase and B-phase. When currents for A-phase and B-phase are determined, those for -A-phase and -B-phase are automatically

25   determined. As described above, the vertical magnetic flux density and the horizontal magnetic flux density each has an almost sine wav distribution with the

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cycle of L. If sine wave control is so performed as to supply to each coil a current in phase with the vertical magnetic flux density distribution, a translational force proportional to the amplitude of sine waves of the current is generated regardless of position.

More specifically, let Y be a position in the view 51a of Fig. 5A, and the position Y is set at 0. If the position Y changes in the direction of an arrow, currents having respective phases can be given by:

A-phase current: $IA = Ic \times \cos((Y/L) \times 2 \times \pi)$

...(1)

B-phase current: $IB = Ic \times \sin((Y/L) \times 2 \times \pi)$

...(2)

-A-phase current: current reverse to A-phase current ...(3)

-B-phase current: current reverse to B-phase current ...(4)

Currents according to expressions (1) to (4) are supplied, a translational force of a magnitude proportional to a current Ic can be generated in the $\pm$ Y directions regardless of position.

When control is so performed as to supply to each coil a current in phase with the horizontal magnetic flux density distribution, a substantially constant levitation force or a force in a direction opposite to the levitation forc can be generated regardless of

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position. More specifically, the position Y in the view 51a of Fig. 5A is set at 0. If the position Y changes in the direction of an arrow, currents having respective phases can be given by:

5
A-phase current: $IA = Ic \times \cos((Y/L) \times 2 \times \pi + (\pi/2))$

$= Ic \times \sin((Y/L) \times 2 \times \pi)$

$\ldots(5)$

B-phase current : $IB = Ic \times \sin((Y/L) \times 2 \times \pi + (\pi/2)))$

$= Ic \times \cos((Y/L) \times 2 \times \pi)$

10
$\ldots(6)$

-A-phase current: current reverse to A-phase

current $\ldots(7)$

-B-phase current: current reverse to B-phase

current $\ldots(8)$

15 Currents according to expressions (5) to (8) are supplied, a force (a levitation force or a force in a direction opposite to the levitation force) of a magnitude proportional to the current Ic can be generated in the $\pm Z$ directions regardless of position.

20 Note that the current Ic has an arbitrary value in expressions (1), (2), (5), and (6).

Each coil layer comprising almost oblong coils whose linear portions are parallel to the X direction, as shown in the view 51a of Fig. 5A, can generate a

25 force of an arbitrary magnitude in the $\pm Y$ or $\pm Z$ directions.

Lik wise, each coil layer (e.g., Fig. 3A)

comprising almost oblong coils whose linear portions are parallel to the Y direction can generate a thrust, a levitation force, or a force in a direction opposite to the levitation force having a magnitude proportional

5 to the current Ic in the $\pm$X or $\pm$Z directions.

As described with reference to Fig. 4B, the lower surface of the top plate 112 is not entirely covered with magnets and has linear defective regions. Even if a current is supplied to each portion without any

10 magnet, neither a thrust nor a levitation force is generated. Current application is so controlled as to prevent a current from being supplied to a portion corresponding to each defective region. In other words, control is performed such that only coils facing

15 magnets are energized.

Fig. 5B is a control block diagram for controlling to drive the movable element 110. A current controller 500 applies the currents defined by expressions (1) to (8) at predetermined timings to an

20 A-phase coil (502), a -A-phase coil (504), a B-phase coil (506), and a -B-phase coil (508). The value of each current generated by the current controller 500 is controlled on the basis of a control command value 501 output from an apparatus controller 510 which controls

25 the entire apparatus, position detection information 503 (503a to 503c) of the movable elem nt 110 detected by position det ctors 520 (520a to 520c), and posture

information 505 (505a to 505c) of the movable el ment

110 detected by posture detectors 530 (530a to 530c).

In current control, control for supplying a

current to only coils facing magnets is based on an

5   arrangement in which the number of A-phase

(or -A-phase) coils is equal to that of B-phase

(or -B-phase) coils. As described above, if control is

so performed as to supply a current in phase with the

magnetic flux density of coils, an almost predetermined

10   translational force or levitation force can be

generated regardless of position. This requires that

the number of coils corresponding to A-phase is equal

to that of coils corresponding to B-phase. That is,

equalization of the numbers of coils having different

15   phases makes it possible to efficiently utilize a force

generated on the side of A-phase and one generated on

the side of B-phase as a translational force, a

levitation force, and the like.

At this time, on/off control for equalizing the

20   number of A-phase coils with that of B-phase coils will

be described with reference to Figs. 6A, 6B, 7A, and 7B.

<ON/OFF Control>

Figs. 6A and 6B are views for explaining

switching of energization for a coil array to generate

25   a translational force. The relationship between the

permanent magnet arrays 114 arranged on the surface, of

the movable element 110 (th lower surface of th top

plate 112), facing the stator 100 and coils arranged on
the base 118 of the stator 100 is shown within an X-Y
plane. As described with reference to Fig. 4A, 14
small magnetic units (601 to 614) are arranged on the

5   lower surface of the top plate 112. Each small
magnetic unit comprises 33 magnets in total: four
magnets magnetized in the +Z direction; four magnets
magnetized in the -Z direction; nine magnets magnetized
at an angle of -45° with respect to the X direction;

10   six magnets magnetized at an angle of 45° with respect
to the X direction; six magnets magnetized at an angle
of 135° with respect to the X direction; and four
magnets magnetized at an angle of -135° with respect to
the X direction. The on/off control of the coils

15   facing the small magnet units is performed such that
only A-phase coils and B-phase coils or -A-phase coils
and -B-phase coils equal in number act on each small
unit.

The equal number is one for one layer, and the

20   on/off control of coils is performed such that one
A-phase (or -A-phase) coil and one B-phase
(or -B-phase) coil act on each small unit.

Switching from the ON state to the OFF state or
from the OFF state to the ON state is performed for

25   coils to which no current is supplied.

Fig. 6A is a vi w with a focus on a state in
which the movable element 110 moves in a direction

(movable element moving direction) of an arrow with
respect to the Y-axis. In Fig. 6A, each energized coil,
i.e., each coil in the ON state is indicated by a
double line (each -B-phase coil is in the ON state) or
5   a wide solid line (each A-phase coil in the ON state)
while each coil in the OFF state is indicated by a
solid line. At this time, each -A-phase coil is in the
OFF state (solid line), and each A-phase coil is in the
ON state (wide solid line). If sine wave control is so
10   performed as to supply to each coil a current in phase
with the vertical magnetic flux distribution, a
translational force of a magnitude proportional to the
amplitude of sine waves of the current can be generated
regardless of position. Accordingly, when the movable
15   element 110 is located at a position shown in Fig. 6A,
current control is performed such that a current having
the maximum value is supplied to each B-phase coil,
whose linear portion is located immediately above
magnets magnetized in the $\pm Z$ directions. Control is
20   also performed such that no current is supplied to each
A-phase coil, whose linear portion is located between
magnets magnetized in the $\pm Z$ directions. The current
controller 500 performs switching from the ON state to
the OFF state or from the OFF state to the ON state for
25   coils to which no current is supplied. That is, in a
state immediately before the movable element 110 moves
to the position shown in Fig. 6A, ach -A-phase coil is

in the ON state; and each A-phase coil, the OFF state.

Coils outside the movable element 110 are all in the OFF state regardless of whether ±A-phases or ± B-phases. The current controller 500 performs current

5   control in accordance with expressions (1) to (4). A current to be supplied to each A-phase coil or B-phase coil is defined by one of the sine and cosine functions depending on the position of the movable element.

In this state, when the movable element moves

10 further downward, it shifts to a state shown in Fig. 6B. At this time, no current is supplied to each B-phase coil or -B-phase coil. When the movable element 110 is located at a position shown in Fig. 6B, each -B-phase coil, which has been in the ON state in Fig. 6A, is

15 changed from the ON state to the OFF state while each B-phase coil, which has been in the OFF state, is changed from the OFF state to the ON state. The on/off control is performed by repeating the same procedures. This makes it possible to control one A-phase

20 (or -A-phase) coil and one B-phase (or -B-phase) coil to act on each small unit described with reference to Figs. 4A and 4B. As a whole, control can be performed such that the A-phase (or -A-phase) coils and B-phase (or -B-phase) coils equal in number act. For this

25 reason, a translational force in the ±Y directions of a magnitude proportional to a predetermined command value can be generated regardless of the position of

the movable el ment 110.

Figs. 7A and 7B are views for explaining
switching of energization for a coil array to generate
a levitation force. A switching method to be employed
5   is the same as in Figs. 6A and 6B. Switching is
performed such that one A-phase (or -A-phase) coil and
one B-phase (or -B-phase) coil act on each small unit.
Control is performed such that the on/off switching
occurs at positions to which no current is supplied.
10   Note that generation of a translational force is
different from that of a levitation force in positions
to which no current is supplied.

As for a translational force, control is
performed such that no current is supplied to each coil
15   whose linear portion is located midway between magnets
magnetized in the Z direction and ones magnetized in
the -Z direction. As for a levitation force, control
is performed such that no current is supplied to each
coil whose linear portion is located immediately above
20   magnets magnetized in the ±Z directions. The case of
a translational force is shifted from that of a
levitation force, by an interval of L/4 in the Y-axis
direction, in positions to which no current is supplied
in the relationship between the linear portions of
25   coils and magnets magnetized in the ±Z directions.

Assume that the movabl el ment moves in a
direction of an arrow with respect to th Y-axis, as in

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Figs. 6A and 6B. In Fig. 7A, switching is performed

such that each -A-phase (B-phase) coil is changed to

the OFF state while each A-phase (-B-phase) coil is

changed to the ON state. Then, the movable element 110

5   moves in a movable element moving direction indicated

by the arrow (Fig. 7B). When the linear portions of

each -B-phase coil and each B-phase coil come to

immediately above magnets magnetized in the $\pm Z$

directions, each -B-phase (-A-phase) coil is switched

10 to the OFF state while each B-phase (A-phase) coil is

switched to the ON state. By repeating the same

procedures, a force in the Z direction of a magnitude

proportional to a command value can be generated

regardless of position.

15   The above description has exemplified a case

wherein the linear portions of coils are arranged

parallel to the X-axis direction. The same applies to

a coil array whose linear portion is parallel to the Y

direction. This case can generate a translational

20 force in the $\pm X$ directions and a levitation force in

the $\pm Z$ directions each having a magnitude proportional

to a command value regardless of position.

        As can be seen from the above, the entire stator

has three layers of coil arrays which generate a

25 translational force in the $\pm X$ directions and a force

in the $\pm Z$ directions and three layers which gen rate a

translational force in the $\pm Y$ directions and a force

in the ±Z directions. The movable element 110 can be
translated, levitated, or rotated by forces with three
degrees of freedom, i.e., in the X, Y, and Z directions
alone or in combination.

5   More specifically, as shown in Fig. 2, the first
coil array which is closest to the magnets and
comprises almost oblong coils whose linear portions are
parallel to the Y direction performs translation and
levitation in the X-axis direction. The second coil
10   array which is below and adjacent to the first coil
array and comprises almost oblong coils whose linear
portions are parallel to the X-axis direction performs
translation and levitation in the Y-axis direction.
The third coil array which is below and adjacent to the
15   second coil array and comprises almost oblong coils
whose linear portions are parallel to the Y direction
performs translation and levitation in the X-axis
direction.

          Control for generating moments to control
20   rotation will be described with reference to Figs. 8 to
10.

          Fig. 8 is a view for explaining generation of
moments about the Z-axis. In a layer comprising almost
oblong coils whose linear portions are parallel to the
25   X direction, a current is supplied to only coil
s gments (801 and 802) which face regions having
defectiv portions out of the magnet-b aring surface of

- 27 -

the movable el ment 110. In addition, coil

energization control is performed such that

translational forces in opposing directions are

generated in the coil segments, respectively. The

5   partial absence of magnets can cause the lines of

action of the translational forces in the opposing

directions to shift in the X direction, thereby

generating moments about the Z-axis (ωz direction).

More specifically, the moments about the Z-axis can be

10   generated using the fourth coil array shown in Fig. 2.

Current control and switching of coils are performed in

the same manner as described above, and a description

thereof will be omitted.

Fig. 9 is a view for explaining generation of

15   moments about the X-axis. In a layer comprising almost

oblong coils whose linear portions are parallel to the

X direction, only coil segments (910 and 911) which

face a central portion free from defective portion but

having eight small magnet units (901 to 908) out of the

20   magnet-bearing surface of the movable element 110 are

driven to generate a force in the $\pm Z$ directions. Coil

energization control is so performed as to generate

forces in the opposing Z directions centered on a

center line G of the movable element. When the movable

25   element shifts from the center line G in the Y

direction, the forces in the opposing Z directions

caus moments for rotating the movable el ment 110

about the X-axis (ωx direction). More specifically, the moments about the X-axis can be generated using the sixth coil array shown in Fig. 2.

5   Fig. 10 is a view for explaining generation of moments about the Y-axis. In a layer comprising almost oblong coils whose linear portions are parallel to the Y direction, only coil segments (1010 and 1012) which face a central portion free from defective portion but having eight small magnet units (1001 to 1008) out of

10   the magnet-bearing surface of the movable element 110 are driven to generate a force in the $\pm Z$ directions. Coil energization control is so performed as to generate forces in the opposing Z direction with respect to a center line G of the movable element.

15   When the movable element shifts from the center line G in the X direction, the forces in the opposing Z directions cause moments for rotating the movable element 110 about the Y-axis (ωy direction). More specifically, the moments about the Y-axis can be

20   generated using the fifth coil array shown in Fig. 2.

Each of the forces in six axial directions has a magnitude proportional to the current and can isolate vibrations between the movable element and the stator.

A flat motor can comprise the movable element 110

25   which comprises only the top plate 112 and magnet arrays 114 asymmetrically arranged on the top plate and the stator 100, in which the (first to sixth) coil

arrays formed by a plurality of coil layers comprising

the almost oblong coils 116 whose linear portions are

parallel to the X or Y direction are fastened to the

base 118. Controlling a current to be supplied to the

5   coil arrays in this flat motor can provide the movable

element 110 with a Lorentz force with six degrees of

freedom. This force is used as a driving force for

performing translation, levitation, or posture control

for the movable element. The position detectors 520

10   (520a to 520c) and posture detectors 530 (530a to 530c)

shown in Fig. 5B measure the position and posture of

the movable element 110 and feed them back to the

current controller 500. This makes it possible to

control the position and posture at high accuracy as

15   desired.

As described above, this embodiment can directly

generate thrusts and moments in directions with six

degrees of freedom and eliminates the need for guiding

power cables. This can provide an alignment apparatus

20   which does not use the air pressure to levitate the

movable element. Disturbance caused by guiding power

cables can be eliminated, thereby allowing

high-accuracy alignment in six axial directions.

<Explanation of Modification>

25   Figs. 11A and 11B are views showing a

modification of the above-mention d embodiment. The

movable element 110 is assumed to have the same

arrangement as that of the embodiment. This modification is different from the embodiment in that a stator 200 has four layers of coil arrays, as shown as an enlarged view of coil arrays 117 in Fig. 11B. The

5 modification has four layers in total: two layers each comprising almost oblong coils whose linear portions are parallel to the X direction; and two layers each comprising almost oblong coils whose linear portions are parallel to the Y direction. The embodiment has

10 the six separate layers as coil arrays to generate forces with six degrees of freedom while this modification has four layers each of which generates forces with two degrees of freedom.

Fig. 12 is a view for explaining control of

15 rotational driving about the Z-axis. A current to be supplied to a coil layer comprising almost oblong coils whose linear portions are parallel to the X direction, i.e., the second coil array in Figs. 11A and 11B is controlled such that only coils (1220 and 1230) which

20 face the movable element 110 are driven using the coil array and that separate translational forces are generated with respect to a center line G in the upper and lower halves of the movable element 110, respectively. The sum of components in translational

25 directions of forces generated by control currents to be supplied to the coil 1220 corresponding to the upper half of the movable element 110 and the coil 1230

corresponding to the lower half becomes a translational
force in the Y direction.

The first translational force (Y-axis) in a
translational Y-axis direction is generated by the coil
5   array 1220 which faces small magnet units (1201 to
1207) on the upper half of the movable element 110, and
the second translational force (Y-axis) in the
translational Y-axis direction is generated by the coil
array 1230 which faces small magnet units (1208 to
10   1214) on the lower half. The presence of defective
portions causes the lines of action of the first
translational force (Y-axis) and the second
translational force (Y-axis) to shift in the X
direction. Hence, a difference between the first
15   translational force (Y-axis) and the second
translational force (Y-axis) acts as a couple of forces
to generate rotation moments about the Z-axis.

Fig. 14 is a view for explaining control of
translational driving in the X-axis direction and
20   rotational driving about the Z-axis. A current to be
supplied to a coil layer comprising almost oblong coils
whose linear portions are parallel to the Y direction,
i.e., the first coil array in Fig. 11B is controlled
such that only coils (1420 and 1430) which face the
25   movable element 110 are driven using the coil array and
that separate translational forces are generated with
respect to a center line G in the upper and lower

halves of the movable element 110, respectively. The
sum of components in translational directions of forces
generated by control currents to be supplied to the
coil 1420 corresponding to the upper half of the

5   movable element 110 and the coil 1430 corresponding to
the lower half becomes a translational force in the X
direction.

The first translational force (X-axis) in a
translational X-axis direction is generated by the coil

10   array 1420 which faces small magnet units (1401 to
1407) on the upper half of the movable element 110, and
the second translational force (X-axis) in the
translational X-axis direction is generated by the coil
array 1430 which faces small magnet units (1408 to

15   1414) on the lower half. The presence of defective
portions causes the lines of action of the first
translational force (X-axis) and the second
translational force (X-axis) to shift in the Y
direction. Hence, a difference between the first

20   translational force (X-axis) and the second
translational force (X-axis) acts as a couple of forces
to generate rotation moments about the Z-axis.

Fig. 13 is a view for explaining control of
translational (levitation) driving in the Z-axis

25   direction and rotational driving about the X-axis. A
curr nt to b supplied to a coil layer comprising
almost oblong coils whose linear portions are parall l

to the X direction, i.e., the fourth coil array in
Fig. 11B is controlled such that only coils (1320 and
1330) which face the movable element 110 are driven
using the coil array and that separate levitation

5   forces are generated with respect to a center line G in
the upper and lower halves of the movable element 110,
respectively. The sum of components in the Z
directions of forces generated by control currents to
be supplied to the coil 1320 corresponding to the upper

10   half of the movable element 110 and the coil 1330
corresponding to the lower half becomes a levitation
force in the Z direction.

The first levitation force in the Z-axis
direction is generated by the coil array 1320 which

15   faces small magnet units (1301 to 1307) on the upper
half of the movable element 110, and the second
levitation force in the Z-axis direction is generated
by the coil array 1330 which faces small magnet units
(1308 to 1314) on the lower half. The presence of

20   defective portions causes the lines of action of the
first levitation force and the second levitation force
to shift in the Y direction. Hence, a difference
between the first levitation force and the second
levitation force acts as a couple of forces to generate

25   rotation moments about the X-axis.

Fig. 15 is a view for explaining control of
translational (levitation) driving in the Z-axis

direction and rotational driving about the Y-axis. A

current to be supplied to a coil layer comprising

almost oblong coils whose linear portions are parallel

to the Y direction, i.e., the third coil array in

5   Fig. 11B is controlled such that only coils (1520 and

1530) which face the movable element 110 are driven

using the coil array and that separate levitation

forces are generated with respect to a center line G in

the upper and lower halves of the movable element 110,

10   respectively. The sum of components in the Z direction

of forces generated by control currents to be supplied

to the coil 1520 corresponding to the upper half of the

movable element 110 and the coil 1530 corresponding to

the lower half becomes a levitation force in the Z

15   direction.

The third levitation force in the Z-axis

direction is generated by the coil array 1520 which

faces small magnet units (1501 to 1507) on the upper

half of the movable element 110, and the fourth

20   levitation force in the Z-axis direction is generated

by the coil array 1530 which faces small magnet units

(1508 to 1514) on the lower half. The presence of

defective portions causes the lines of action of the

third levitation force and the fourth levitation force

25   to shift in the X direction. Hence, a difference

between the third l vitation force and the fourth

levitation forc acts as a coupl of forces to generate

rotation moments about th Y-axis.

According to the arrangement described in this
modification, the number of coil layers on the stator
side can be reduced. From another point of view, if
5 the cross-sectional area of six coil layers falls
within the tolerance, the cross-sectional coil area per
layer can be increased by a factor of 1.5 (= six
layers/four layers). This can decrease the resistance
of coils and then the amount of heat generated upon
10 supplying a current to the coils.
<Application to Semiconductor Exposure Apparatus>

Reference numeral 1601a denotes a view showing
the arrangement in which a twin-stage alignment
apparatus comprising two movable elements and a stator
15 according to the arrangement of the above-mentioned
embodiment or modification is applied to a
semiconductor exposure apparatus. Reference numeral
1601b in Fig. 16A denotes a view showing a state
wherein two movable elements 1630a and 1630b are
20 aligned within a plane on a coil array 1640 of a stator
1660. A wafer chuck (not shown) is mounted on each of
the movable elements 1630a and 1630b, and a wafer as an
object to be exposed is placed on the wafer chuck.
Mirrors (not shown) are arranged on the side and upper
25 surfaces of the top plate (corresponding to the top
plate 112 in Fig. 1) of each of the movable elements
1630a and 1630b to detect the position and posture of

the movabl element. For example, use of a laser
interferometer can measure the position and posture of
the movable element with six degrees of freedom (the
measurement means (520a to 520c and 530a to 530c) shown
5   in Fig. 5B).

The entire semiconductor exposure apparatus
comprises a measurement region 1670 which measures by a
measurement optical system 1610 the position of an
exposure pattern exposed by an exposure optical system
10   1620 and an exposure region 1680 which exposes a wafer
to a semiconductor circuit pattern by the exposure
optical system 1620. A means (not shown) for
loading/unloading a wafer into/from the semiconductor
exposure apparatus is arranged on the left side of the
15   measurement region 1670. As indicated by an arrow in
the view 1601a of Fig. 16A, the apparatus is arranged
to perform loading/unloading of the wafer in the
measurement region 1670.

The movable elements 1630a and 1630b have the
20   same arrangement as that of the embodiment. The
principle of force generation of the coil array 1640 of
the stator 1660 is the same as that of the embodiment.
The apparatus is characterized by its arrangement and
can implement both a function of freely moving and
25   aligning the two movable elements 1630a and 1630b in
ach of the measur ment region 1670 and exposure region
1680 and a function of moving the two movable el ments

1630a and 1630b from the exposure region 1680 to the
measurement region 1670 or from the measurement region
1670 to the exposure region 1680.

The stator has a stacked structure of four or six
coil layers each comprising almost oblong coils,
similarly to the embodiment and modification.

As shown in Fig. 17A, a layer comprising almost
oblong coils whose linear portions are parallel to the
X direction is divided into two, left and right
portions to correspond to the measurement region 1670
and exposure region 1680 in the view 1601b of Fig. 16A.
This division into the two portions makes it possible
to separately control the forces in six axial
directions for each of the two movable elements 1630a
and 1630b even when they are horizontally aligned in
the plane.

When the layer is not horizontally divided into
two portions, and the two movable elements 1630a and
1630b are horizontally aligned, they share almost
oblong coils whose linear portions are parallel to the
X direction. This disables independent control of the
forces in the six axial directions for each of the
movable elements 1630a and 1630b. In the semiconductor
exposure apparatus, when the two movable elements are
independently moved in the exposure region 1680 and
measurem nt region 1670, they may horizontally be
aligned. For this reason, in a coil array layer

comprising almost oblong coils whose linear portions
are parallel to the X direction, as shown in Fig. 17A,
division of the almost oblong coils into two right and
left portions is absolutely required to independently
5   control the two movable elements.

As shown in Fig. 17B, a layer comprising almost
oblong coils whose linear portions are parallel to the
Y direction has a region 1730 in which the linear
portions of coils are vertically divided into two
10   portions. In the region 1730, in which the coils are
vertically divided into two portions, the forces in the
six axial directions for each of the two movable
elements 1630a and 1630b can independently be
controlled when the two movable elements are vertically
15   aligned, i.e., their X-coordinates are almost the same,
and their Y-coordinates are different from each other.
For example, in a region like a region 1740 in which
almost oblong coils whose linear portions are parallel
to the Y direction are not vertically divided into two
20   portions, when the two movable elements are aligned
horizontally in the Y direction, they share coils whose
linear portions face the movable elements. This
disables independent control of the forces generated by
the coils and then separate control of the forces in
25   the six axial directions for each of the movable
el ments.

When the two movable elements are moved from the

exposure region 1680 to the measurement region 1670 or from measurement region 1670 to the exposure region 1680, a situation in which the two movable elements are aligned vertically in the Y direction may occur

5 inevitably. For this reason, to generate a force which allows the two movable elements to move independently in the X direction, the region 1730, in which almost oblong coils whose linear portions are parallel to the Y direction are vertically divided into two portions,

10 as shown in Fig. 17B, is absolutely necessary.

Operation of the movable elements 1630a and 1630b will be described with reference to Figs. 18A to 20B.

In Fig. 18A, the first movable element 1630a is located in the exposure region 1680, and the second

15 movable element 1630b is located in the measurement region 1670. A wafer being exposed is placed on the first movable element 1630a. The first movable element 1630a performs operation of aligning/transporting the wafer with/to a predetermined position in the exposure

20 region. The exposure optical system 1620 exposes the wafer on the first movable element 1630a in the exposure region 1680. An exposed wafer is placed on the second movable element 1630b. The measurement optical system 1610 measures the position of a pattern

25 on the exposed wafer in the measurement region 1670. When a wafer unloading means (not shown) unloads the exposed wafer after the measurement, a wafer loading

m ans (not shown) loads a wafer to be exposed into a wafer chuck (not shown) on the second movable element 1630b.

5   When the exposure process in the exposure region 1680 is completed by driving the movable element 1630a, and the measurement process in the measurement region 1670 is completed by driving the second movable element 1630b, wafer unloading and loading are independently performed. After that, the movable elements 1630a and 10   1630b move to the measurement region 1670 and exposure region 1680, respectively. When the movable elements 1630a and 1630b pass by each other, as shown in Fig. 18A, the first movable element 1630a moves upward while the second movable element 1630b moves downward 15   so as to prevent collision. At this time, each of the first movable element 1630a and second movable element 1630b may take the reverse refuge route. As shown in Fig. 18B, the first movable element 1630a so moves as to pass by on the upper side of the vertically divided 20   coils shown in Fig. 17B, and the second movable element 1630b so moves as to pass by on the lower side of the vertically divided coils. At this time, the two movable elements desirably pass by each other to have almost rotational symmetry.

25   For example, as shown in Fig. 19, assume that the two movable elements do not hav almost rotational symmetry in a positional relationship betwe n the coil

array layer in Fig. 17B and the movable elements. In
this case, the upper and lower movable elements have a
deviation (δ). If one of the movable elements enters
the driving force region of the other movable element,

5   the two movable elements are present in the region of
the coil array which generates the same driving force.
This disables independent control of stages. To
prevent such a state, the movable elements 1630a and
1630b are controlled to wait until they enter the

10   states shown in Figs. 18A and 18B.

         After the movable elements 1630 pass by each
other, the second movable element 1630b enters the
exposure region 1680 and starts exposure processing.
In the measurement region 1670, the wafer on the first

15   movable element 1630a is measured by the measurement
optical system 1610. The wafer having undergone the
measurement is unloaded from the wafer chuck (not
shown), and a new wafer is loaded. Measurement and
exposure are performed on the basis of the independent

20   driving of the two movable elements. When the
above-mentioned arrangement is employed, wafers are
placed on the movable elements, respectively. This
allows parallel processing of exposure and pattern
position measurement and an increase in productivity of

25   semiconductor exposure apparatuses.
<Modification of Layout of Movable Element Magnets>
         Figs. 20A and 20B, and 21A and 21B are views

showing modifications of the layout of magnets arranged

on a movable element. Fig. 20A shows the arrangement

described in the embodiment, which has the defective

portions A and B, and regions C to H. Magnets may be

5   arranged in the regions C to H, as shown in Fig. 20B.

In this case as well, control for driving the movable

element is the same as described above. In the magnet

arrangement (Fig. 20A) according to the embodiment,

magnets are divided into small magnet units each

10   comprising 33 magnets. In the arrangement of Fig. 20A,

magnetic fluxes decrease in each edge portion of each

small magnet unit. In the arrangement of Fig. 20B, the

edge portions of the small magnet units are eliminated

by filling the linear regions C to H with magnets.

15   This prevents a decrease in magnetic fluxes in each

edge portion of each small magnet unit. The uniformity

of forces generated between movable element magnets and

stator coils can be increased.

Figs. 21A and 21B are views showing other

20   modifications of the layout of movable element magnets.

In the arrangement (Fig. 4B) described in the

above-mentioned embodiment, the defective portions A

and B are arranged in the upper right and lower left

corners on a diagonal line to generate rotation moments

25   about the Z-axis. The positions of defective portions

are not limited to those shown in Fig. 4B. For example,

in Fig. 21A, def ctive portions (2110a and 2110b) are

arranged at positions shifted inward in a movable

element plane. Alternatively, defective portions may

be arranged at positions indicated by 2110c and 2110d,

respectively, i.e., positions not on a diagonal line in

5   a movable element plane.

As described above, even when defective portions

are arranged at different positions, in a certain layer,

translational forces in opposing directions by

supplying currents in opposing directions to a coil

10   array which faces two defective portions or separate

translational forces are generated on the upper and

lower halves of a movable element with respect to the

center line, similarly to the embodiment. With this

operation, rotation moments about the Z-axis can be

15   generated by separately controlling currents to be

supplied to coil arrays.

Fig. 27 is a view showing another modification of

the layout of movable elements. In the foregoing

description, cases are exemplified as modifications of

20   the layout of magnets wherein defective portions are

arranged differently. The modification shown in

Fig. 27 has no defective portion but has projecting

regions (2701 and 2702) on a movable element. Movable

element magnets are arranged in these regions (to be

25   referred to as "projecting regions" hereinafter).

In a layer comprising almost oblong coils whose

linear portions are parallel to the X direction, a

current is supplied to only coil segments (2703 and 2704) which face regions having projecting regions out of the magnet-bearing surface of the movable element 110. In addition, coil energization control is

5   performed such that translational forces in opposing directions are generated in the coil segments, respectively. Since the projecting regions 2701 and 2702 are shifted in the X and Y directions and are arranged at different X- and Y-coordinates, reverse

10 translational forces act. This can generate moments about the Z-axis (ωz direction). Current control and switching of coils are performed in the same manner as described above, and a description thereof will be omitted.

15   Additionally, the actions of moments about other driving axes (ωx and ωz) are as described above, and a description thereof will be omitted. An arrangement which has projecting regions, as shown in Fig. 27, and controls forces by movable element magnets arranged on

20 these regions to generate moments for controlling the posture of the movable element 110 increases the utilization efficiency of coils on the stator side and reduces the amount of heat generated by coil energization. These effects are unique to this

25 modification.

        According to the arrang m nt shown in Fig. 27, all movabl element magn ts arranged in a region other

than the projecting regions of the movable element 110,
i.e., a central square region 2705 (the first region)
can be used to drive the movable element 110 in a
translational direction. Assume that coils (2703 and

5   2704) which face the projecting region (2701: the
second region) and the projecting region (2702: the
third region) perform rotation about the Z-axis, and
coils which face the central square region 2705 (the
first region) perform translational driving. If the

10   arrangement (Fig. 27) of movable element magnets in
which separate groups of coils contribute to rotation
about the Z-axis and translational driving generate the
same driving force as an example in which defective
portions are present among the movable element magnets

15   (e.g., Fig. 8), the amount of heat generated by coils
reduces to 1/2. In the example in which defective
portions are present among the movable element magnets
(e.g., Fig. 8), the number of movable element magnets
in the region 803 (Fig. 8) without any defective

20   portion is half that of movable element magnets
arranged in the square region 2705. To generate the
same driving force as that obtained by the arrangement
of Fig. 8 using the arrangement of Fig. 27, the coil
resistance (R) of movable element magnets increases

25   twice while the current (I) decreases to 1/2.
Consequently, th amount of heat ($Q = I^2 \cdot R$) of all the
coils decreases to 1/2.

Figs. 28 and 29 show other arrangem nts in which projecting regions are arranged at different positions. In the arrangement shown in Fig. 28, projecting portions (2801 and 2802) are shifted from those of the

5   arrangement shown in Fig. 27 by X1 in the -X direction and X1 in the +X direction, respectively. In the arrangement of Fig. 29, projecting portions (2901 and 2902) are shifted from those of the arrangement shown in Fig. 28 by X2 in the -X direction and X2 in the +X

10 direction, respectively. When the positions of the projecting regions are so shifted as to approach a central axis (center of gravity) G2 in the Y-axis direction, the moments of inertia about the Y-axis of the movable element 110 can be reduced. This

15 relationship can also be obtained by bringing projecting regions close to the central axis in the X-axis direction. Even when moments for causing rotation are small, posture control can effectively be performed by reducing the moments of inertia. Also,

20 even when projecting regions as shown in Figs. 28 and 29, driving control is performed and the amount of heat generated in the driving control decreases, in the same manner as that in Fig. 27.

As described above, when movable element magnets

25 for generating moments about the Z-axis to control the posture are to be arranged, defective portions may be provided in the plane surface of a movable element or

projecting regions may b provided, as shown in Figs. 27 to 29. Projecting regions need to have arrays of magnets which face stator coils, and each array needs to have an array interval equal to that of

5 movable element magnets arranged in the square region 2705 (the first region). The planar shape of the movable element 110 within a movable plane, which has projecting regions, is asymmetric, i.e., linearly asymmetric with respect to axes (G1 and G2) passing

10 through the central portion (center of gravity) GP of the square region 2705 (the first region) and is almost rotationally symmetric with respect to the central portion GP. A rotationally symmetric shape is preferable because the rotation center and the position

15 of the center of gravity readily coincide with each other.

<Structure for Cooling Coils>

In the above-mentioned embodiment, modification, application to the semiconductor exposure apparatus,

20 each movable element magnet generates translational, levitation, and rotational driving forces by a magnetic force generated by a predetermined control current supplied to a stator coil array. Since each of these driving forces is generated by a Lorentz force, the

25 amount of heat increases with an increase in load on coils. Cooling coils to remove generated heat allows a large current to flow in coils. In addition, thermal

disturbance can be reduced in a measurement environment

for measuring the position of a movable element.

Fig. 22 is a view showing the arrangement which

directly cools coils by a coolant 2240. In addition to

5   the arrangement according to the embodiment, a

partition 2210 with which the coil arrays 116 are

enclosed and which are isolated from the base 118 is

provided. The inside of the partition is filled with a

coolant 2240 such as Florinert, pure water, or the like.

10 The coolant 2240, which has been temperature-controlled

by a circulating system (not shown), circulates from a

coolant inlet 2220 toward a coolant outlet 2230.

Directly cooling the coil arrays 116 by the coolant

2240 can effectively reduce a rise in temperature of

15 coils.

Fig. 23 is a view showing the arrangement which

indirectly cools coils through a thermal conductor 2310.

Similarly to the arrangement in Fig. 22, the partition

2210 with which the coil arrays 116 are enclosed and

20 which are isolated from the base 118 is also provided.

The inside of the partition 2210 is filled with the

thermal conductor 2310 having high thermal conductivity.

A coolant 2340 is arranged to circulate through a

channel which is provided in the base 118 and extends

25 from a coolant inlet 2320 toward a coolant outlet 2330

by a circulating system (not shown). In this

arrangement, the base 118 is first cooled, and coils

can indirectly be cooled by heat conduction through th

thermal conductor 2310. The coil temperature in this

arrangement is higher than the arrangement in Fig. 22.

However, since coils and the coolant do not come in

5   contact with each other, insulation countermeasures can

easily be implemented, and countermeasures against a

leak of the coolant are unnecessary. Additionally,

since the partition does not receive the internal

pressure of the coolant, the thickness of the partition

10   can be reduced.

<Application to Semiconductor Manufacturing Process>

The manufacturing process of a semiconductor

device (e.g., a semiconductor chip such as an IC or

LSI, a CCD, or a liquid crystal panel) using the

15   above-mentioned exposure apparatus will be described

with reference to Fig. 16B.

Fig. 16B shows the flow of the whole

manufacturing process of the semiconductor device. In

step 1 (circuit design), a semiconductor device circuit

20   is designed. In step 2, exposure control data for an

exposure apparatus is created on the basis of the

designed circuit pattern. In step 3 (wafer

manufacture), a wafer is manufactured by using a

material such as silicon. In step 4 (wafer process)

25   called a preprocess, an actual circuit is formed on the

wafer by lithography using the pr par d mask and wafer.

Step 5 (assembly) called a post-proc ss is the step of

forming a s miconductor chip by using the wafer formed
in step 4, and includes an assembly process (dicing and
bonding) and packaging process (chip encapsulation).
In step 6 (inspection), the semiconductor device
5   manufactured in step 5 undergoes inspections such as an
operation confirmation test and durability test. After
these steps, the semiconductor device is completed and
shipped (step 7).

The wafer process in step 4 comprises the
10 following steps. More specifically, the wafer process
includes an oxidation step of oxidizing the wafer
surface, a CVD step of forming an insulating film on
the wafer surface, an electrode formation step of
forming an electrode on the wafer by vapor deposition,
15 an ion implantation step of implanting ions in the
wafer, a resist processing step of applying a
photosensitive agent to the wafer, an exposure step of
transferring the circuit pattern onto the wafer having
undergone the resist processing step using the
20 above-mentioned exposure apparatus, a development step
of developing the wafer exposed in the exposure step,
an etching step of etching a portion except for the
resist image developed in the development step, and a
resist removal step of removing an unnecessary resist
25 after etching. These steps are repeated to form
multiple circuit patterns on the wafer.

With the above-mentioned exposure apparatus, the

exposure accuracy and the throughput of the apparatus can be increased. This can increase the productivity of semiconductor devices compared to the prior art.

As has been described above, the present

5 invention can generate thrusts and moments in directions with six degrees of freedom and eliminates the need for guiding power cables. This can provide an alignment apparatus which does not use the air pressure to levitate a movable element.

10 Alternatively, disturbance caused by guiding power cables can be eliminated, thereby allowing high-accuracy alignment in six axial directions.

Alternatively, to arrange magnets on a movable element, ones which generate a translational driving

15 force and the remaining ones which generate a rotational driving force in a projecting region of the movable element are separately arranged. This can reduce the amount of heat generated in coils upon driving of the movable element.

20 As many apparently widely different embodiments of the present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the

25 claims.